

**CHARACTERIZATION OF FUNCTIONAL PROPERTIES OF
BREADFRUIT FLOUR (ARTOCARPUS ALTILIS)**

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ABSTRACT

Breadfruit (*Artocarpus altilis*) has been a traditional Pacific Islander crop producing 100 to 600 fruits a year. A single breadfruit weighs between 1 to 4 kg on average. Post-harvest, the fruits ripen quickly (1 to 3 days) and deteriorates after a week, resulting in short shelf life. One way to extend shelf life of fruit was to solar dry fruit in small pieces and mill it into flour. The purpose of this study was to determine if flour made from breadfruit could increase utilization of this crop. Understanding these properties will help determine the functioning and gelatinization properties of whole and cored ‘Ma‘afala’ cultivar breadfruit flour was evaluated.

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LIST OF SYMBOLS AND ABBREVIATIONS

ΔH	– Gelatinization Enthalpy
ΔT	– Temperature Range
AM	– Amylose
AP	– Amylopectin
CBF	– Cored Breadfruit Flour
DSC	– Differential Scanning Calorimeter
LGC	– Least Gelation Capacity
PHI	– Peak Height Index
T_c	– Conclusion Temperature
T_o	– Onset Temperature
T_p	– Peak Temperature
WAC	– Water Absorption Capacity
WBF	– Whole Breadfruit Flour
WHC	– Water Holding Capacity

CHAPTER 1

LITERATURE REVIEW

1.1 - General Breadfruit Introduction

Breadfruit has been considered a steady and staple carbohydrate crop for centuries to many islanders around the Oceania. Reports have indicated the tree is multi-dimensional; various parts of the plant have been researched for extensive uses such as mosquito repellent (Jones and others 2012), medicine (Bipat and others 2008; Bourdy and others 1992; McClatchey 1993; Ragone 1997), and woodcraft applications (McCoy and others 2010; Meilleur and others 2015). However, the fruit is the most desired part of the tree for human consumption. Extensive research has been done on several breadfruit species in the Pacific such as *Artocarpus camansi*, *Artocarpus altilis*, *Artocarpus mariannensis*, and the hybrids, *altilis* x *mariannensis*. Breadfruit was once seen as an icon or the gateway to the Pacific by European explorers. As of recent past these fruits were underutilized due to the preference and importation of wheat and rice to many tropical countries, causing many breadfruit trees and special cultivars to disappear overtime. Considering recent studies on the nutritional analysis of breadfruit, potential marketability is indicated for the future. In this research, it will focus primarily on the breadfruit species *Artocarpus altilis* and one of its cultivars, ‘Ma‘afala’.

1.1.1 - Origins

Many have discussed the origins of breadfruit to be somewhere near the Oceania. Recent studies have started to put the pieces together regarding breadfruit’s evolution and worldly

voyage. Using genetic markers, Zerega and others (2004, 2005) revealed that *A. altilis* species was derived from its wild ancestor *A. camansi*, also called breadnut, species with large and numerous seeds, native to New Guinea and perhaps to the Moluccas and the Philippines. Further research findings have shown seeded *A. altilis* was first domesticated in New Guinea and in the neighboring region, the Bismarck Archipelago (Ragone 1997) and by Oceanic Austronesian people (Kirch 1997; Lebot 1999), later associated archaeologically with the Lapita complex culture (Blust 1995). The Lapita people were known for their distinctive pottery; they were horticulturalists and expert seafarers who lived around Near Oceania (the Bismarck Archipelago and the Solomon Islands archipelago). Tree crops such as breadfruit were grown in permanent “orchard gardens” near the settlements (Kirch 1997). Many centuries ago starting around 1200 B.C., the Lapita and their ancestors ventured out into remote (east of the Solomon Islands) Oceania and migrated throughout the Pacific carrying domesticated animals and plants for the long journey (Kirch 2000).

For plants, such as breadfruit to survive longer ocean voyages eastward into distant islands of Melanesia and Polynesia in remote Oceania, a shift to root propagation was necessary because seeds were short-lived. As breadfruit dispersed eastward, seedless (triploids [3n]) cultivars became more favorable than seeded (diploid [2n]) cultivars heading towards Polynesia (Fig 1.1). Between eastern Solomon Islands and western Polynesia, a large diversity of seedless and a few-seeded breadfruit cultivars grew including the adaptation from seeds to root propagation (Ragone 1997, 2001; Zerega and others 2004, 2006). However, the preference for seedless cultivars were seen in eastern Polynesia where a complete shift to root propagation transformed breadfruit into a staple crop and eventually, the most sought out cultivars that drew interest from people beyond the Pacific.

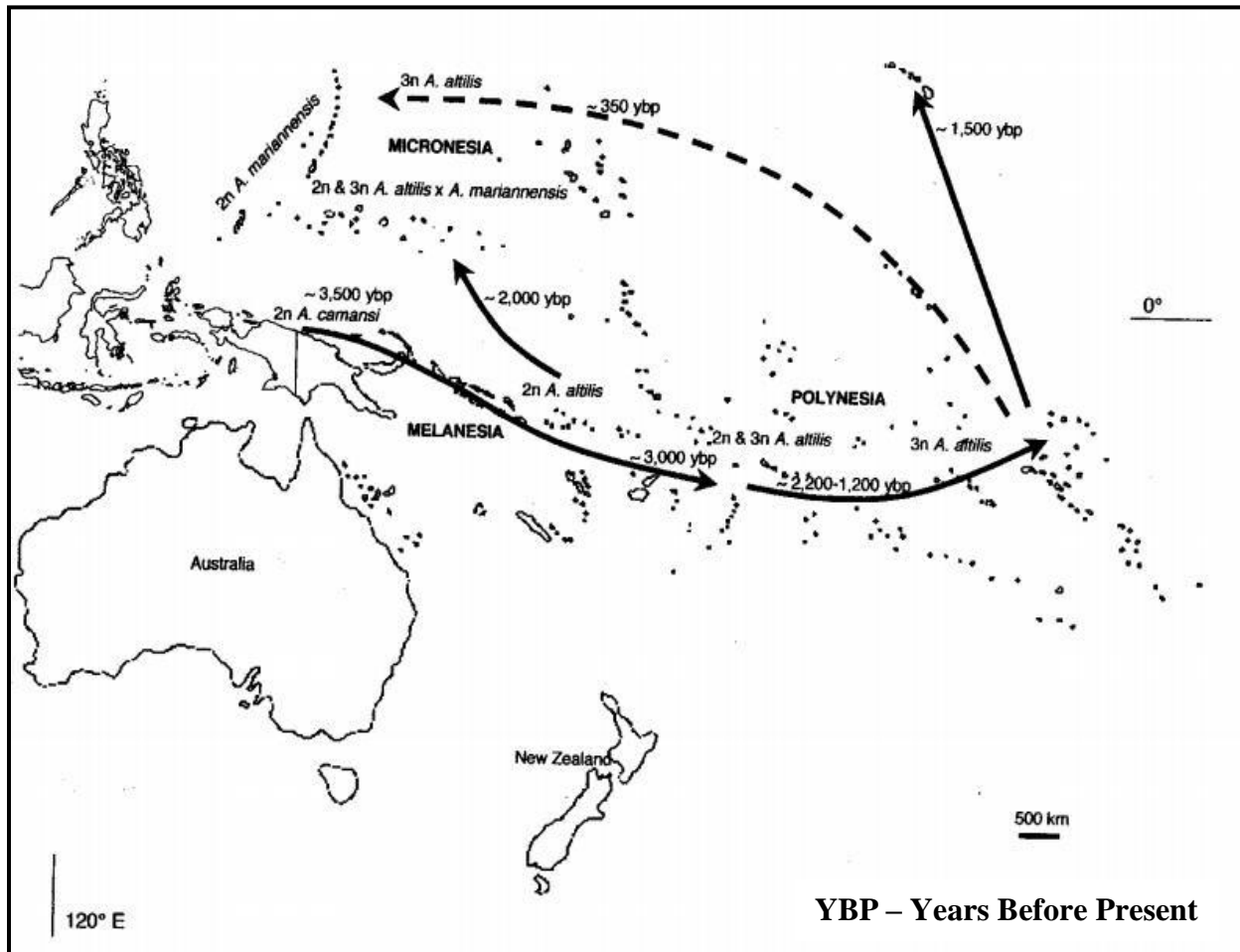


Figure 1.1. Map of Oceania with proposed human-mediated breadfruit dispersal routes (Zerega and others 2006)

1.1.2. Historical Distribution

Breadfruit was an exclusive staple crop in the Pacific until European explorers began to journey into the region late 1600s. The potentials of breadfruit were not fully understood until the 17th century when a British botanist named Sir Joseph Banks took interest in the plant. In 1768, Sir Joseph Banks joined Captain Cook's first expedition on the *HMS Endeavor* to the south pacific. The trip had two purposes; the first was to establish an observatory on Tahiti and to search for the southern continent if one existed (Cook and Price 1971; SLNSW 2016). Upon

reaching Tahiti, the natives received Captain Cook and his crew and presented them with gifts, one gift being breadfruit. Banks and the crew were captivated by a tree that could produce fruits that when roasted, reminded them of freshly baked bread (NTBG 2016a; Ragone 1997). He also recognized the abundance and potentials of breadfruit and how it could be utilized in other tropical areas. Once Banks returned home, he proposed to King George III for an expedition to transport breadfruit plants from the Pacific to the slave colonies in the British West Indies to combat famine (DeLoughrey 2007; NTBG 2016a; Powell 1977).

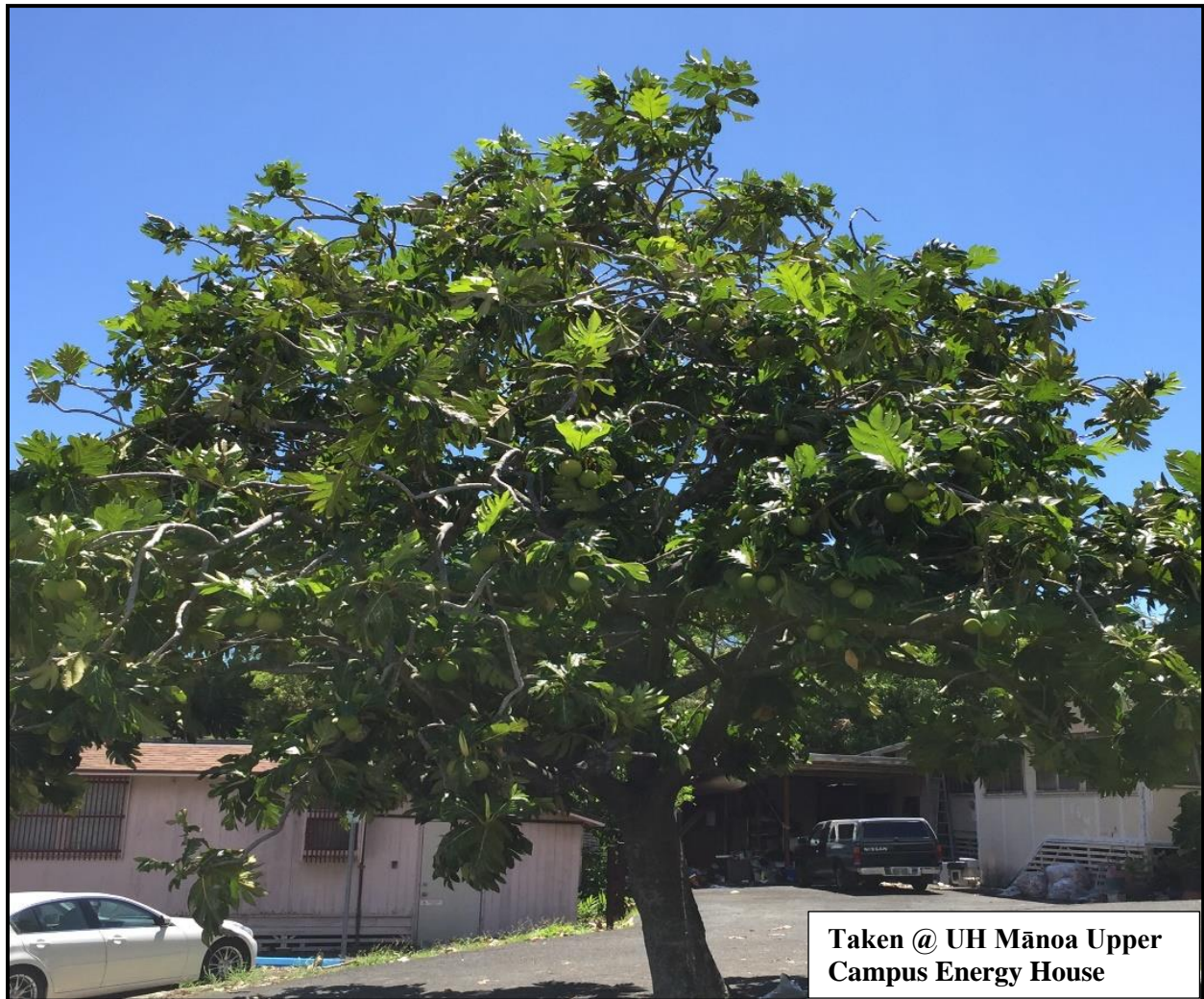
Captain William Bligh led the special expedition to the South Pacific. It took two voyages to transport breadfruit from Tahiti to the British West Indies. The first voyage (1787-1790) ended with the infamous mutiny of the *HMS Bounty* where breadfruit saplings were thrown overboard. The second voyage (1791-1794) upon the *HMS Providence*, successfully delivered its breadfruit cargo to St. Vincent and Jamaica in the British West Indies (DeLoughrey 2007; Howard 1997; Powell 1977). In the Pacific, hundreds of breadfruit cultivars exist, but Bligh only brought a few seedless cultivars to the Caribbean where only four or five cultivars are recognized today (Leakey 1977; Powell 1977). From there, these breadfruit cultivars were distributed throughout Africa, Caribbean, Central and South America, India, Indonesia, Madagascar, northern Australia, Southeast Asia, Sri Lanka, the Seychelles, south Florida, and the Maldives by various European travelers and explorers (Ragone 1997, 2006, 2011) to areas that were or currently being threatened by famine (NTBG 2016b). The one common trait these places possess for breadfruit to thrive is climate conditions.

1.1.3. Botanical Characteristics

Breadfruit (*Artocarpus altilis*) is a large tropical flowering tree in the mulberry family (Moraceae) and a producer of edible fruits. The plant favors wet tropics with average temperatures between 21 to 32°C and bimodal annual rainfall between 1,500 to 3,000 mm and latitudinal limits are about 17°N and 17°S (Ragone 1997, 2006, 2011; Singh and others 1963). The physical outlook of the breadfruit tree is displayed in Fig 1.2. The structure of the tree by maturity is dome-shaped and is typically 12 to 15 m (40 to 50ft) in height and form natural canopies. Breadfruit trees require good drainage, but with adequate water from rainfall or ground water. Benefits of breadfruit trees include watershed protection, erosion control, and windbreaks. The natural canopy of the breadfruit tree helps other plants thrive and protect human infrastructures from the sun by providing shade (Meilleur and others 2015; Ragone 1997, 2006, 2011; Singh and others 1963). After sprouting, the tree begins to produce flowers that eventually become green spherical fruit (Fig 1.3). When breadfruit trees are capable of bearing fruit, they can continuous produce breadfruit for 35 to 60 years when healthy, resulting in slower planting turnover (Meilleur and others 2015).

The distinct characteristics of the fruit vary based on cultivar; size, weight, shape, flesh, and skin. Hundreds of cultivars have been named based on these characteristics. Some cultivars, such as ‘Ma’afala’, ‘Maopo’, and ‘Puou’ are examples of named widely distributed cultivars in the Pacific Islands perpetuated by vegetative propagation (Ragone 2011). These cultivars are seedless and are originally from Polynesia. Out of these three cultivars, ‘Ma’afala’ is the smallest (12 to 16 cm x 10 to 13 cm) and lightest (0.6 to 1.1 kg). ‘Ma’afala’ and ‘Maopo’ are oval fruits with white flesh, while ‘Puou’ is oval with creamy-pale yellow flesh (NTBG 2016c; Ragone

2011). These characteristics go beyond physical attributes; the nutritional content of each cultivar varies as well.



**Taken @ UH Mānoa Upper
Campus Energy House**

Figure 1.2. Breadfruit Tree (*Artocarpus altilis*)



Figure 1.3. A fruit growing on the breadfruit tree (*Artocarpus altilis*)

1.1.4. Production and Seasonality

Breadfruit trees are very productive and why they have been considered a staple crop in the Pacific Islands. Yields vary depending upon cultivar, age, tree health, and growing conditions. An average-sized tree can produce about 100 fruits per year. Larger trees can yield 400 to 600 fruits, there have been reports of 700 to 900 fruits per year (Colins 2016; Marte 1986; NTBG 2016b; Purseglove 1968; Ragone 1997, 2006, 2011). On average, the weight of fruit is between 1 to 4 kg, but has been reported to reach up to 6 kg (Meilleur and others 2015; Ragone 1997, 2006). Therefore, one mature breadfruit tree can produce from 400 to 2400 kg of breadfruit in a year. These production numbers are greater compared to other starch sources on

the islands such as cassava and yam because of its verticality of production. The edible portion for seedless cultivars is approximately 70% of the fruit with skin, stem, and core removed (Ragone 1997).

Breadfruit can be produced year-round due to cultivar diversity with different fruiting seasons. However, few breadfruit growing regions have adequate cultivar diversity for year-round production (Atchley and Cox 1985; Jones and others 2010). Listed in Table 1.1 is the seasonality and origins of the different seedless *A. altilis* cultivars in the Pacific. As noted, most breadfruit cultivars have a main fruiting season between July and November followed by a second smaller season earlier in the year.

1.1.5. Developmental Stages (Ripeness)

Once the tree starts producing flowers, they will eventually become fruit. Breadfruit goes through five main stages of development: flowering, immature, full size green, mature, and ripe (Fig 1.4). The fruit takes at least sixteen weeks to reach maturity followed by four additional weeks to become ripe (Elevitch and others 2014). When harvested, the ripening phase decreases shelf life is severely shortened to a matter of hours or days depending on the stage it was picked. The fruit can be consumed at any stage of development; mature fruits are the most preferred stage of consumption followed by the ripe stage (Elevitch and others 2014). Mature fruits are used in a wide variety of dishes as a potato-like starch including salad, fries, curry, soups, stews, chips, and other processed food products (Elevitch and others 2014; Ragone 1997, 2011). Ripe fruits are much sweeter than mature ones and are specifically used for desserts such as sweet baked goods pies, and puddings among other food products as of contemporary development (Elevitch and others 2014; Ragone 1997).

Table 1.1. Fruiting season of various breadfruit (*Artocarpus altilis*) cultivars adapted from (NTBG 2016c)

Cultivar Name	Origin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Afara	French Polynesia	+++				+		+++	+++	+++	+++	+++	+++
Lemae	Mariana Islands							+++		+		+++	
Ma'afala	Samoa	+	+	+	+	+		+++	+++	+++	+++	+++	+++
Maopo	French Polynesia	+++				+++	+++	+++	+++	+++	+++	+++	+++
Meiarephe	Federated States of Micronesia	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Meitehid	Federated States of Micronesia	+++	+++	+++	+	+		+++	+++	+++	+++	+++	+++
Meiuhpw	Federated States of Micronesia						+++	+++	+++	+++	+++	+++	
Oteo	French Polynesia	+++	+++			+		+++	+++	+++	+++	+++	+++
Puaa	French Polynesia									+++	+++	+++	
Puou	Samoa					+		+++	+++	+++	+++	+++	+++
Toneno	French Polynesia				+++	+++	+++	+++	+++	+++	+++	+++	+++
Ulu	Hawaii	+++	+				+	+++	+++	+++	+++	+++	+++
Ulu fiti	Fiji	+						+	+++	+++	+++	+++	+++
Ulu tala	Samoa		+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	
White	Seychelles	+++				+	+	+++	+++	+++	+++	+++	+++

+++ , Main fruiting month; + , Few fruits produced

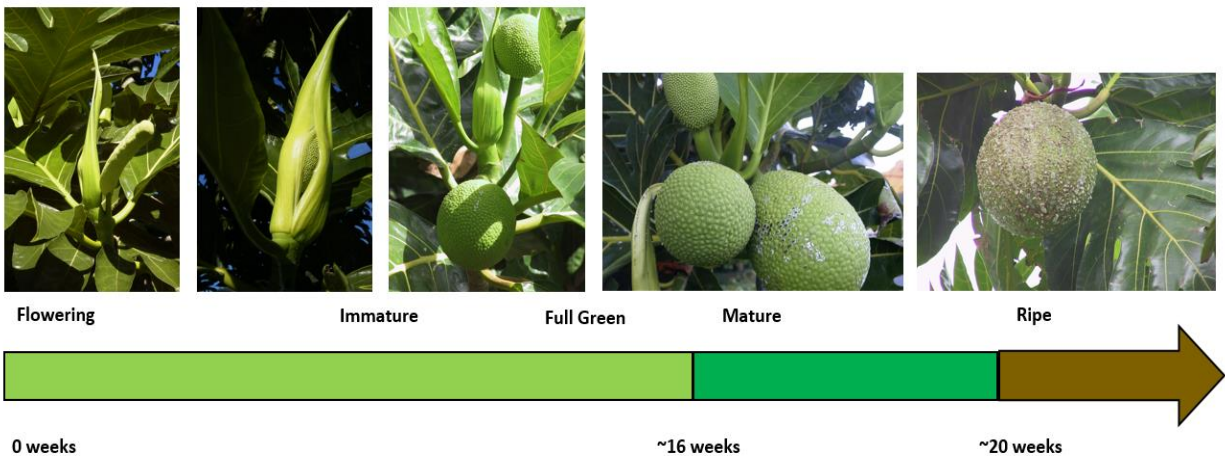


Figure 1.4. Five Developmental Stages of Breadfruit

1.1.6. Nutritional Considerations

Breadfruit is a good carbohydrate source supplying about as much energy as most staple crops (USDA 2016). A recent study showed the starches of ‘Local Yellow’, ‘Hope Marble’, ‘Creole Doyle’, ‘Common’, and ‘Ma‘afala’ cultivars were classified as very low amylose (2 to 9%) while ‘Local White’, ‘Kashee Bread’, ‘Jackson Macca’, ‘Timor/ St. Kitts’, ‘Cassava Murray’, and ‘Pii Piia’ were classified as low amylose (10 to 20%) (Broomes and others 2015).

Additionally, breadfruit is gluten free and can be utilized in a variety of products to substitute or partially replace for wheat. It is also worth noting that nutritional (i.e. carbohydrate, protein, lipid, vitamin, and mineral) composition change by stage of ripeness (Aalbersberg and others 1988; Englberger and others 2003a; Golden and Williams 2001; Graham and Bravo 1981; Jones and others 2013a).

Minerals found in breadfruit include: copper, magnesium, phosphorous, potassium, calcium, cobalt, iron, and manganese, but amounts are highly variable associated to growth

location and cultivar (Huang and others 2000; Jones and others 2013b; Jones and others 2011; Morton 1987; Ragone 1997, 2011; Ragone and Cavaletto 2006).

Carotenoid content has been investigated to alleviate vitamin A deficiency in malnourished parts of the world. Significant amounts of carotenoids have been detected in some breadfruit cultivars (Englberger and others 2014; Jones and others 2010; Ragone and Cavaletto 2006). A study showed the cultivar, 'Mejwaan' (3540 µg/100 g), has exceptionally rich beta-carotenoid content (Englberger and others 2013); other cultivars such as 'Mei kole' (1260 µg/100 g), and 'Mekinono' (1050 µg/100 g) have high carotenoid content (Englberger and others 2007). Ripened breadfruit contains higher levels of carotenoids than mature breadfruit (Aalbersberg and others 1988; Englberger and others 2003a; Huang and others 2000; Ragone and Cavaletto 2006). Even though the color of the fruit is intense and rich yellow as it continues ripening, it does not correspond with higher carotenoid content (Englberger and others 2003b).

Breadfruit contains all essential amino acids (Golden and Williams 2001; Liu and others 2015; Morton 1987). A recent study was conducted on the quality of essential amino acids from 49 important breadfruit cultivars (Liu and others 2015). Their findings showed that all varieties contained a full spectrum of amino acids, the cultivar 'Ma'afala' (Samoa) contained significantly higher total essential amino acid content than other varieties.

1.1.7. Food Security

High yield and energy content of breadfruit make the fruit useful for alleviating food shortage problems in developing countries. Breadfruit however, is underutilized and underappreciated due to negative stigma in many non-pacific island countries (Deivanai and Bhore 2010; Omobuwajo 2003; Ragone 1997; Turi and others 2015; Wootton and Tumaalii

1984). Throughout history, breadfruit was considered a “poor man’s food” since it was associated with slavery, food shortages, and poverty (Roberts-Nkrumah 2007). As economic conditions improved and lifestyles changed, staple foods and diets changed as well. Importation of the more preferred wheat, rice, and other cereal and non-cereal grains to island nations replaced the original intent of breadfruit to combat mass starvation (Balick 2009; Roberts-Nkrumah 2007; Thorburn and others 1987). Thus, many breadfruit trees were destroyed over time for other rapid yielding carbohydrate plants (Colins 2016).

Recently, breadfruit is starting to regain its role in world hunger initiatives in tropical and subtropical countries. Dr. Diane Ragone, Breadfruit Institute director, has mass propagated breadfruit trees and sent these to famine problem regions such as the Africa, Asia, Caribbean, Central America, and Oceania (NTBG 2016b). The breadfruit cultivar, ‘Ma’afala’, is the most exported and favorable because of its greater protein and mineral content compared to other cultivars (Jones and others 2012; Letman 2012; Liu and others 2015; NTBG 2016b).

1.1.8. Major Limitations in Harvest and Post-Harvest

One major limitation in harvesting the fruits from the breadfruit trees is the height of the tree. Despite an abundance of fruits can be harvested on a yearly basis, the plant is still approximately 12 to 15 m (40 to 50ft) in height when it matures. Several techniques have been employed to harvest breadfruit, typical harvesting tools include a long pole with a forked end and a grip bag to catch the fruit (Ragone 1997, 2011; Ragone and Raynor 2009). Another practical way of collecting fruit is using tripod orchard ladders, allowing the collector to safely pick fruits since it is designed to be used on uneven or rough terrain (Ragone 2011). None of these

techniques are fast nor efficient. Current tools are limited by the inability to harvest the upper canopy where about 50% of the fruit can be located (Roberts-Nkrumah 2007).

The second major drawback is the shelf-life of the fruit. Breadfruit is highly perishable; post-harvest, the fruit ripens in 1 to 3 days followed by rapid starch deterioration after a week. Soft, ripe breadfruits are undesirable for consumption which leads to substantial loss of production. This problem greatly restricts marketability and exportation outside production areas since fruits will ripen before reaching their destination (Ragone 1997). Breadfruit can be placed in cold storage to prolong shelf life and firmness for an additional 9 days at 12 to 13 °C (Maharaj and Sankat 1989; Worrell and others 2002). Many locations where breadfruit are typically grown lack the necessary modern day refrigeration equipment and utilities to store large fruit quantities during the hot and humid harvesting season (Ragone 2011; Ragone and Raynor 2009).

1.1.9. Fruit to Breadfruit Flour

Breadfruit over ripens in just a few days, causing the fruit to become undesirable and tossed as food waste. A solar dehydration process was recently developed in American Samoa to reduce moisture content in breadfruit as shown in Fig 1.5. Reducing moisture content in breadfruit helps create a shelf-stable product by preventing continued ripening and microorganism growth (Amusa and others 2002; George and others 2007; Rowe and others 2007). The use of a solar dehydrator is the simplest, most cost- and energy-efficient means of processing sliced or shredded raw breadfruit especially in communities that require all the resources they can use (George and others 2007; Ragone 2011). The fruits are dried at 65 °C to reduce nutrient damage. Once breadfruit is dried to acceptable levels, it can be used in various ways. Dried fruit can be consumed or used as it is or milled in a grinder as flour.

The utility of breadfruit flour is still being investigated, so far products such as bread (Malomo and others 2011), biscuits (Agu and others 2007; Eke-Ejiofor 2013; Olaoye and others 2007), cake (Bakare and others 2013; Eke-Ejiofor 2013), cookies (Akubor and Badifu 2004), pasta (Oduro and others 2007), porridge (Mayaki and others 2003), and instant baby food (Esparagoza and Tangonan 1993) have been looked into, however it was used mainly as a flour replacer in bakery products.

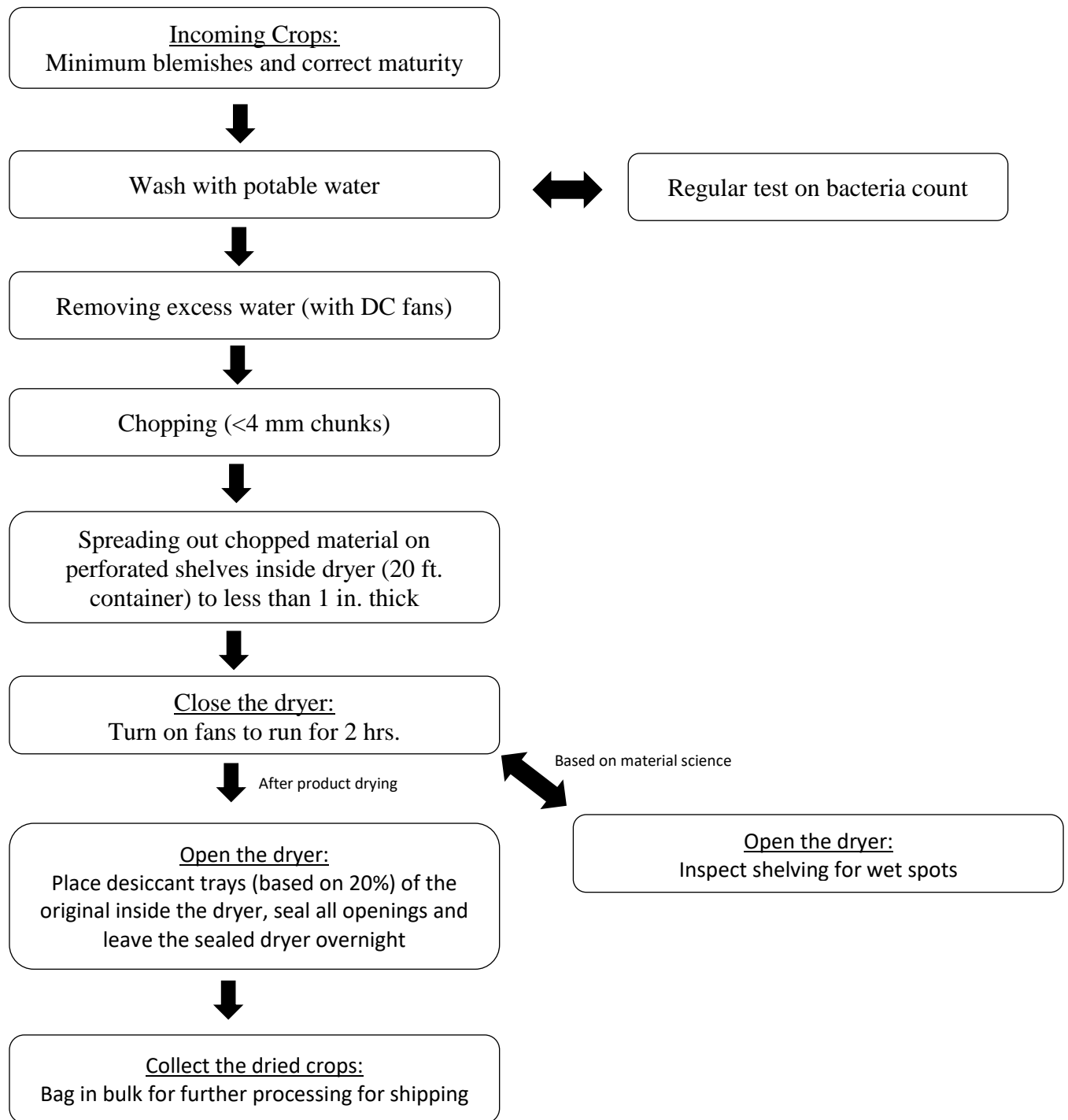


Figure 1.5. Flow chart of the solar dehydration process used in American Samoa

1.2. The Structure of Starch

Starch is a carbohydrate produced by plants as long-term energy storage; it is used as an ingredient primarily in baked products as well as a thickener in viscous foods. These small polymers are an important energy source in human nutrition and are found in cereals (A-type starch), tubers (B-type starch), and legumes (C-type starch, a mixture of A and B-type starch) in small packets called granules. Starch granules occur in all sizes ($<1\ \mu\text{m}$ to $100\ \mu\text{m}$) and shapes (spheres, ellipsoids, polygon, and irregular tubulars) depending on the botanical source and species (Belitz and others 2009; BeMiller and Whistler 2009; Jane and others 1994; Pérez and Bertoft 2010; Stark and Lynn 1992; Vamadevan and Bertoft 2015).

Starch exists in its native form as semi-crystalline granules with a large complex network of D-glucose monomers connected by glycosidic bonds that form two different but closely related

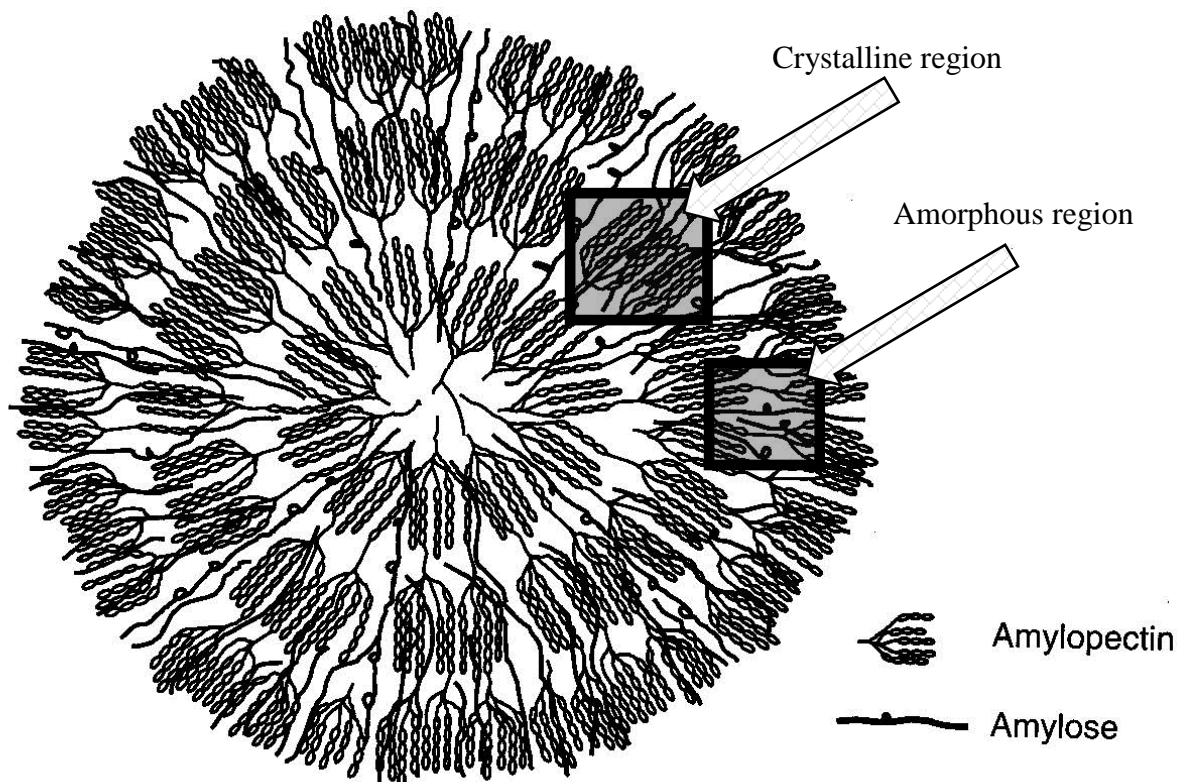


Figure 1.6. Schematic of the organization of a starch granule (BeMiller and Whistler 2009)

molecules, amylose (AM) and amylopectin (AP) (Fig 1.6). Amylose is the minor component of most starch species, typically 15 to 35% of the starch (BeMiller and Whistler 2009; Pérez and Bertoft 2010), some waxy varieties contain very little, or if any, AM (<1%), and other starches, such as amylomaize, contains about 65% AM (Parker and Ring 2001). They are generally linear chains of α -(1, 4)-linked D-glucose monomers, some molecules have been found to be slightly branched by α -(1, 6)-linkages (Buléon and others 1998; Kjølberg and Manners 1963; Takeda and others 1987). Amylopectin (AP) is the major component of the granule that typically makes up the remaining 65 to 85% of the starch. AP are highly branched polysaccharides that consists of short chains of α -(1, 4)-linked D-glucose monomers that are interconnected through α -(1, 6)-linkages (Belitz and others 2009; Brady 2013; Pérez and Bertoft 2010). Starch granules consist of both crystalline and amorphous regions; AP chains are the backbone of the starch granules' crystalline region. The finer structure of AP determines the crystalline type and organization (existence of double helices) of the starch granule.

1.2.1. Starch Properties

Starch properties can vary depending on the botanical source and species, the molecular composition, and the structure of the components. These properties are of considerable importance for diverse applications of starch. Vamadevan and Bertoft (2015) indicates that starches have industrially interesting properties. These properties include: “gelatinization and swelling of the starch granules, and the retrogradation, pasting, and freeze-thaw stability of the solubilized starch components.”

The study of functional attributes in starch-water systems are mostly related to the processes known as gelatinization, pasting, and gelation (retrogradation) (Atwell and others 1988; Dengate 1984). When starch is heated in an aqueous solution, it undergoes an endothermic process called gelatinization. This process disrupts the molecular orders within the starch granule causing irreversible changes in properties such as granular swelling, native crystallite melting, loss of birefringence, and higher viscosity (Atwell and others 1988; Carlstedt and others 2015; Fredriksson and others 1998; Singh and others 2003; Wang and Copeland 2013).

Several factors have been researched that affect the gelatinization process: AM and AP characteristic and water composition related to hydration of non-starch ingredients. In starch gelatinization process, AM-AP ratio and chain length greatly influence the outcome. Starches with higher AP ratio such as waxy starches require higher energy to gelatinize than their normal counterparts (Fredriksson and others 1998; Klucinec and Thompson 2002). However, Noda and others (1998) reported that it was not the quantity of the AM-AP ratio that affects gelatinization, but rather distribution of AP branch chains. Similar results were reported by Jane and others (1999). Trends based on AP branch chain-length have been investigated. Each starch with the same crystalline type have been observed to have their own chain-length distribution (Jane and others 1999). Waxy starches exhibit larger gelatinization temperatures and enthalpies, reflecting a higher percentage crystallinity of AP (Villwock and others 1999). However longer branch AP chain length, such as high-AM maize and potato starch require larger amounts of energy to gelatinize crystallites of longer chain lengths (Jane and others 1999; Shi and Seib 1995).

Water content is another important variable when studying the gelatinization process. Prior to gelatinization, starch granules absorb water into its amorphous region and increase in size by 30%. Once heated, the granule swells due to the properties of AP (Tester and Morrison

1990a, 1990b). Water acts a plasticizer in starch gelatinization to aid in the disassociation of polymer-polymer bonds through polymer-hydrogen bonding. Starch requires water content at least 40% to enhance the gelatinization process (Ismail and others 2016). Eliasson (1980) used a differential scanning calorimeter (DSC) to observe the gelatinization process of wheat starch using various (35 to 80% w/w) water content levels. They found when water content decreased, a second and third endotherm appeared. The appearance of the endotherms is caused by different starch populations gelatinizing in relations to uneven water distribution within the amorphous region (Biliaderis and others 1980; Burt and Russell 1983). Similar results were found with the addition of gluten (Eliasson 1983) and fibers (Chen and others 1988; Normand and Marshall 1989; Santos and others 2008) into the starch-water system. It was indicated that adding non-starch ingredients into the system effects water availability. Before gelatinization, rehydration of hydrophilic proteins and dietary fibers is prioritized.

After starch gelatinizes and subsequently cooled, disrupted AM and AP chains gradually recrystallizes into a different structure known as retrogradation. Retrogradation is a challenge for food manufactures since it determines the quality and shelf-life of finished foods (Biliaderis 1991; Wang and Copeland 2013). Starch retrogradation usually leads to undesirable effects which can cause reduced shelf life, negative impact on consumer acceptance, and eventually food waste (Wang and others 2015). Foods such as staling of bread and other starchy foods and thinning of starch-based soups are examples of retrogradation. When AM and AP chains realign, several changes are seen such as increase viscosity, opacity and gel firmness, and phase separation between polymer and water (syneresis) (Wang and Copeland 2013). Generally, higher AM starches recrystallize to a higher degree than starches with a larger AP ratio (Fredriksson and others 1998; Jane and others 1999). AP on the other hand recrystallizes within the starch

granule. The short branches of AP molecules form double helices that become ordered crystalline clusters (Keetels and others 1996). Short-term storage leads to retrogradation of mainly AM, whereas recrystallization of AP side chains is much slower (Wang and Copeland 2013). Additives such as carbohydrates (glucose, sucrose, guar gum, etc.), proteins (soy protein, wheat protein, etc.), lipids, and emulsifiers have been used to slow down or inhibit retrogradation in some starch systems, but increase retrogradation in other systems (Wang and others 2015).

1.3. Differential Scanning Calorimetry

Many different measurement techniques have been reported for investigation of starch gelatinization and retrogradation process (Atwell and others 1988; Gill and others 2010; Wang and others 2015). Among them, Differential scanning calorimetry (DSC) traditionally is the most preferred tool when studying thermal transitions in starch (Atwell and others 1988; Wang and Copeland 2013). DSC is advantageous due to its keen sensitivity and precision of thermal analysis to detect phase transitions in the starch granule (Carlstedt and others 2015). It is used to study gelatinization and retrogradation over a wide range of water content while remaining in a sealed container (Eliasson 1980; Gill and others 2010; Ratnayake and others 2009). Thermal readings are based on the effects of aqueous solution to AP structure. Typical data obtained from DSC onset (T_o), peak (T_p), conclusion (T_c), and range temperatures (ΔT) plus gelatinization enthalpy (ΔH) as shown on Fig 1.7 for breadfruit flours. T_o is the beginning of starch gelatinization, T_p is the temperature of maximum heat flow to completely dissociate the AP structure (Wang and Copeland 2013), and T_c or also known as temperature recovery, is when gelatinization ends or return to baseline (Tester and Morrison 1990a). ΔH is the amount of

energy to completely gelatinize the starch samples. Listed on Table 1.2 are gelatinization properties of some common starch sources from various experiments using DSC. Results are not always correct and vary per experiment (i.e. pan size and material, equilibration of sample, and misreading data) (Yu and Christie 2001). However, this method is not overly time consuming and does not require any special training.

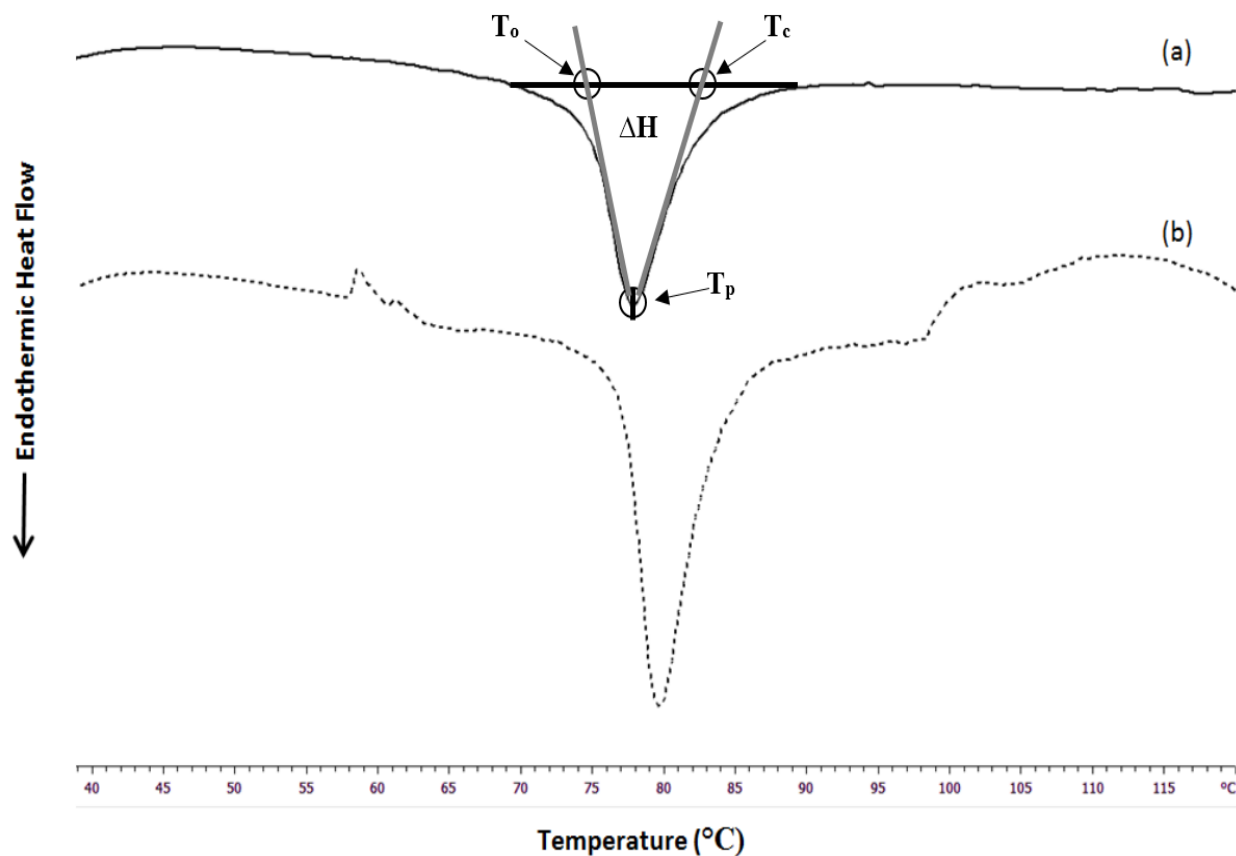


Figure 1.7. A gelatinization thermograph of breadfruit flours: (a) whole and (b) cored

Table 1.2. Gelatinization properties of common starch sources using DSC

Starch	T_o (°C)	T_p (°C)	T_c (°C)	ΔT (T_c - T_o)	ΔH (J/g)
Wheat					
Normal ¹	48.10	53.60	58.20	14.80	14.80
Waxy ¹	51.60	57.00	65.30	13.70	17.90
Maize					
Normal ²	59.00	66.00	73.00	14.00	14.30
Waxy ²	65.00	73.00	82.00	17.00	16.00
Amylomaize ²	63.00	76.00	82.00	19.00	6.30
Potato					
Normal ³	60.80	65.20	70.60	9.80	17.30
Waxy ³	62.50	66.60	70.20	7.70	18.20
Rice					
Normal ⁴	65.60	73.20	80.10	14.50	3.12
Waxy ⁵	46.00	64.30	81.00	35.00	13.40
Cassava ⁶	64.00	70.20	79.10	NA	14.20

T_o, Onset Temperature; T_p, Peak Temperature; T_c, Conclusion Temperature; ΔT, Gelatinization Range; ΔH, Gelatinization Enthalpy

¹Sasaki and others (2000)

²Hoover and Manuel (1996)

³McPherson and Jane (1999)

⁴Chungcharoen and Lund (1987)

⁵Tester and Morrison (1990b)

1.4. Research Justification and Objectives

There are very few studies on the gelatinization and functional properties of breadfruit starch in scientific literature; very few to none mentioned the cultivar used in their studies.

Additionally, there are no studies on the gelatinization and retrogradation properties of breadfruit flour by differential scanning calorimeter and very limited research on its functional properties as of date. The ‘Ma‘afala’ cultivar is a universal breed that is usually sent to various food deficient tropical countries, hence the focus of this research. Breadfruit flour can potentially be used for food formulations as a thickener in viscous foods or a partial flour replacer in bakery products.

Therefore, the specific objectives of this study were:

- 1) To determine gelatinization and retrogradation properties of breadfruit flour milled from the cultivar ‘Ma‘afala’.
- 2) To determine basic functional properties of breadfruit flour (‘Ma‘afala’) and interpretation of data for practical food formulation use.

CHAPTER 2

FUNCTIONAL PROPERTIES AND CULINARY USES OF BREADFRUIT FLOUR (ARTOCARPUS ALTILIS)

2.1. Abstract

Breadfruit has been considered a traditional crop to islanders in the Pacific region for many centuries. It is a large starchy fruit with a few days to few weeks of shelf life. To extend shelf life, whole fruit was solar dried and milled into flour. The aim of the study was to determine functional and thermal properties of whole breadfruit flour (WBF) and cored breadfruit flour (CBF) milled from mature breadfruit of the 'Ma'afala' cultivar. Differential scanning calorimetry (DSC) was used to determine starch gelatinization and retrogradation properties. Results showed that breadfruit flour had higher water absorption capacity (WAC) than commercial all-purpose and bread flours indicating more hydrophilic components are in breadfruit flours. The peak temperature (T_p) of WBF and CBF are 78.2 ± 1.0 and 79.3 ± 0.4 respectively, indicating high energy is needed to gelatinize starch granules in flour. A short retrogradation was evaluated on gelatinized flour samples which had been placed in cold storage for 2 and 4 days at 5 °C, no retrogradation was found. WBF had lower water holding capacity (WHC) than CBF when subjected to heat above 80 °C indicating greater starch content in CBF. Breadfruit flours potentially can be used as a thickener in viscous foods such as soups, sauces, and puddings, and in certain bakery products.

2.2. Introduction

Breadfruit (*Artocarpus altilis*) is a large tropical flowering tree that produces edible fruits. The plant has been considered a traditional staple crop to islanders throughout the Oceania where it was originally domesticated over 3,000 years ago (Ragone 1997, 2011). The trees have great productive ability, producing 100 to 600 green and mature fruits per year (NTBG 2016b). A healthy tree can remain at peak fruiting capacity for 35 to 60 years (Meilleur and others 2015). On average, the fruit weighs between 1 to 4 kg and can reach up to 6 kg (Ragone 1997). Breadfruit is gluten-free and can potentially be used for a wide range of food applications.

Breadfruit has been processed and consumed in many forms, including baked, boiled, mashed, steamed or roasted and consumed with soups or other flavorings. Even though fruit is abundant year round (Jones and others 2010), breadfruit is underutilized and has found limited applications in the food industry (Omobuwajo 2003). A major drawback is the short shelf-life of the fruit. Post-harvest, the fruit ripens in 1 to 3 days followed by rapid starch deterioration after a week. Soft and over-ripened breadfruits are undesirable for consumption which leads to substantial loss. Cold storage can prolong shelf life and firmness for only a few more weeks (Maharaj and Sankat 1989; Worrell and others 2002). However, many locations where breadfruit are grown lack the efficiency to cool large fruit quantities during the hot and humid harvesting season (Ragone 2011; Ragone and Raynor 2009).

There is a need to increase food availability and decrease food waste. One way to extend the shelf life of breadfruit is to dry and turn it into flour. An off-grid solar dehydrator process was recently developed in American Samoa. The function of the solar dehydrator was to dry breadfruit under low heat and in a moisture controlled environment while minimizing utilities.

To determine potential breadfruit flour utilization in food formulations, functional properties of flour before, during, and after gelatinization were identified.

2.3. Materials and Methods

Food Products and Homogenization of Breadfruit Slurries

Freshly harvested mature breadfruits from the ‘Ma’afala’ cultivar was selected from surrounding villages in American Samoa. Fruits were picked 100 days after flowering and breadfruit flour prepared from whole fruit. Fig 2.1 shows a schematic of breadfruit flour preparation for the following experiments.

Preparation and homogenization of breadfruit slurries for water or oil based experiments included a VX100 (Labnet International, Inc., Edison, NJ, U.S.A.) vortex mixer to improve flour-liquid base dispersion, unless otherwise noted.

Preparation of Breadfruit Flour

Mature breadfruits were inspected for blemishes and cleaned with potable water to clear away latex and dirt from the skin. After washing, breadfruits were fan dried to remove excess water. For whole breadfruit flour (WBF), fruits were peeled and chopped into small (<4mm diameter) rough chunks before placed into a solar dehydrator. For cored breadfruit flour (CBF), after peeling, fruits were cored, chopped, and then dried. Breadfruit chunks were dried in low heat (65 °C) and sealed overnight; product was then packed into polyethylene bags. Dried fruits

were then milled into flour and passed through an 80-mesh sieve. Breadfruit flour samples were stored in double layered airlock plastic bags.

Moisture and Total Dietary Fiber Content

Moisture content was determined by an oven drying method 925.09 (AOAC 1995). Total dietary fiber content was determined using an enzymatic-gravimetric method 985.29 (AOAC 2000).

Bulk Density

Bulk density was determined using the method of Okezie and Bello (1988). Results were then calculated as weight of sample per unit volume of sample (g/mL).

Water and Oil Absorption Capacity

Water and oil absorption measurements of the flour samples were adapted from Okezie and Bello (1988) with slight modifications. One gram of breadfruit flour was added to 10 mL of distilled water or canola oil in a 15 mL centrifuge tube and homogenized for 1 min. After homogenization, flour samples were allowed to rest at room temperature for 30 min followed by centrifugation at 5,000 x g. for 30 min. The volume of free water or oil was carefully drained at a 45° angle for 15 min and the sample weighed. To convert to grams, absorbed water or absorbed oil (total minus free water/oil) was multiplied by its density. Density of distilled water is

assumed to be 1 g/mL and canola oil was measured to be 0.88 g/mL. Absorption capacity was expressed as the grams of water or oil retained per gram of flour sample (g/g).

Starch Gelatinization and Retrogradation

To determine thermal phase transitions of starch in flour samples, gelatinization and retrogradation measurements were made by a DSC1 STAR^e system (METTLER TOLEDO, Schwerzenbach, Switzerland). Different water-flour concentrations were tested several times since breadfruit flours contained hydrophilic non-starch ingredients. Breadfruit slurry was created by adding 2 g distilled water into a sterile glass mL vial with 500 mg of breadfruit flour. The slurry was mechanically agitated until flour was completely dispersed into the solution and 6.5 mg of slurry was pipetted into 40 μ l-aluminum pans. The pans were helically sealed and could equilibrate in room temperature for 1 hr. before heating in the DSC system. Nitrogen purge gas was used for temperature calibration and a pan with an equal amount of distilled water was used as the reference. Sample pans were scanned from 20 to 120 °C at a rate of 10 °C/min. Onset (T_o), peak (T_p), and conclusion (T_c) temperatures and gelatinization enthalpy (ΔH) were calculated using Star^e software for thermal analysis. After scanning, samples were stored at 5 °C for 2 or 4 days. To determine retrogradation, stored samples were scanned a second time from 5 to 100 °C at a rate of 10 °C/min using an empty aluminum pan as reference.

Water Holding Capacity (WHC)

Water holding capacity was determined using a combination of Sasaki and Matsuki (1998) and Takahashi and Seib (1988) with slight modifications. One gram of breadfruit flour was added to 14 mL of distilled water in a 15-mL centrifuge tube and homogenized for 30 sec. The slurry was then placed in a thermostatically controlled water bath at a constant temperature (50, 60, 70, 80, and 90 °C) and homogenized every 5 min for 20 min. The tubes were cooled with cold water for 5 min and centrifuged at 1,700 x g. for 15 min. Free water was carefully drained immediately after centrifugation. WHC was determined as the ratio of residue weight (g) divided by sample weight prior to adding distilled water (g).

Least Gelation Capacity (LGC)

Gelling concentration method was determined using the method of Sathe and Salunkhe (1981) with slight modifications. Flour suspensions of 2, 4, 5, 6, 8, 10, and 12 % (w/v) were prepared in 5 mL distilled water and homogenized. The test tubes contained flour suspensions were heated at 95 ± 2.0 °C for 1 hr. followed by cooling in a cold-water bath and placed in cold storage (4 °C) for 2 hrs. LGC was determined as the concentration when the sample from the inverted test tube did not fall or slip.

Statistical Analysis

One-way analysis of variance (ANOVA) using Tukey's Post Hoc test was used to determine mean separation of breadfruit flours and commercial starches/flours. Paired T-test was

used to determine if breadfruit cores (WBF) had significant differences in gelatinization properties versus without cores (CBF). The mean analysis values were compared using SPSS version 24.0 (IBM, Armonk, New York, USA).

2.4. Results and Discussion

Characteristics and Nutrient Content Whole Breadfruit (WBF) and Cored Breadfruit Flour (CBF)

Whole breadfruit flour (WBF) contained about 4.75% more moisture than cored breadfruit flour (CBF) ($12.75 \pm 0.2\%$ vs $7.9 \pm 0.3\%$). The moisture values obtained differed from the values of Adepeju and others (2011) for WBF ($7.78 \pm 0.49\%$) and CBF ($11.42 \pm 0.62\%$) flours. Differences may be due to unremovable skin from the whole fruit for WBF samples, causing moisture to be retained after drying. Protein content ranged from 3.39 to 3.46% for WBF and CBF, respectively and were insignificantly different. These values were similar to those reported by Jones and others (2011) for protein content of breadfruit from the ‘Ma’afala’ cultivar ($3.30 \pm 0.51\%$). Table 2.2 shows fiber and functional characteristic data. Adepeju and others (2011) reported a similar trend that WBF had greater fiber content than CBF, however WBF and CBF of their samples were noticeably less than our samples. Total dietary fiber of breadfruit flours is three times higher than typical commercial bleached all-purpose flour (USDA 2016).

Bulk Density

The results of bulk density, water and oil absorption capacity are listed in Table 2.3. Flours and starches weigh differently per volume measure and can affect translation of food formulations to consumer recipes. Our breadfruit flour showed that WBF had lower bulk density than CBF (0.54 ± 0.0 and 0.64 ± 0.0 , respectively). Both breadfruit flours measured less than all-purpose and bread commercial flours as well as corn and potato starches. Our bulk density data generally agrees with Adepeju and others (2011), however, their WBF bulk density was greater than their CBF sample. Lower flour density may require larger volume packaging material to obtain target constant packaging weight.

Water Absorption Capacity (WAC)

Water absorption capacity was greater in WBF compared to CBF. This greater WAC may be attributed to added fiber from the cores (Table 2.1). Our data agrees with Adepeju and others (2011). Our data showed that breadfruit flours had greater WAC than commercial all-purpose and bread flour. The greater WAC could indicate that total dietary fiber in breadfruit absorbs more water than gluten in all-purpose and bread flours. Bread flour had higher WAC than all-purpose flour due to its higher gluten content.

The ability of flour to absorb more water can improve the consistency and texture in food products. These results suggest breadfruit flour may be useful for food formulations such as partial wheat flour replacer for dough handling in baking and pastry products.

Oil Absorption Capacity (OAC)

Oil absorption capacity was significantly greater in WBF than CBF ($p < 0.05$). Greater oil absorption is typically thought to be a property of protein, depending on its lipophilic/lipophobic amino acid composition. Protein content was shown to be similar in both flours, indicating fibers can trap oil droplets within its fibrous network. Similar data was reported by Adepeju and others (2011) for higher OAC in WBF ($139.9 \pm 1.02\%$) than CBF ($81.62 \pm 0.94\%$). In their sample, WBF had significantly higher fiber content ($5.78 \pm 0.07\%$ versus $2.93 \pm 0.11\%$) and lower protein ($3.79 \pm 0.19\%$ versus $5.49 \pm 0.22\%$) content than CBF. OAC was also shown to be higher in WBF than all-purpose and bread flour, though CBF was unexplainably the lowest (see Table 2.1). The ability of flours to absorb oil is important as it improves texture of various foods such as baking and pastry products for better palatability (Odoemelam 2003).

Starch Gelatinization

Starch gelatinization is a process where the molecular order within the starch granule is disrupted by the presence of excess water and heat. This process causes irreversible changes in properties such as granular swelling and higher viscosity. The concentration 1:4 (wt. %) was selected as the breadfruit slurry remained in an aqueous state. The gelatinization properties obtained by differential scanning calorimetry for WBF and CBF included the onset (T_o), peak (T_p), and conclusion (T_c) temperatures, and gelatinization enthalpy (ΔH); range of gelatinization ($\Delta T = T_c - T_o$) and peak height index (PHI) ($\Delta H/T_r [T_r = T_p - T_o]$) were calculated and are as shown in Table 2.2. Authors could find no other data at this time providing a full gelatinization scan for breadfruit flour. Nwokocha and Williams (2011) reported gelatinization temperatures

(T_o and T_p) and gelatinization enthalpy (ΔH) for breadfruit starch were 66.4, 69.3 °C, and 19.27 J/g respectively, values differed to Koh and Long (2012), T_o , T_p , and ΔH were 71.38, 73.87 °C, and 15.08 J/g respectively. None of these articles mentioned the cultivar(s) used in their gelatinization tests, however results were comparable to our ‘Ma‘afala’ breadfruit flour.

The difference in gelatinization temperatures for breadfruit starches as reported is directly related to its amylopectin (AP) and amylose (AM) ratio. Broomes and others (2015) reported that each breadfruit cultivar differs in AP and AM ratio and the ‘Ma‘afala’ cultivar used for the current gelatinization study contains 2 to 9% AM.

Starch sources with greater levels of AP (Tester and Morrison 1990a) or longer branch chain lengths tend to have higher gelatinization temperatures and enthalpy due to increased intermolecular bonding within the crystalline order (Jane and others 1999; Noda and others 1998; Villwock and others 1999). The ΔH is a measure of the overall crystallinity of the AP, i.e. the quality and quantity of starch crystals (Tester and Morrison 1990a). The data showed lower ΔH and higher gelatinization temperatures in flour samples compared to what was reported for starch (Koh and Long 2012; Nwokocha and Williams 2011). This is due to non-starch (i.e. fiber and protein) components in flour versus starch. When non-starch ingredients absorb and hold onto more water, less water is available for distribution among the starch granules during melting, this creates ungelatinized starch granules within the system. These ungelatinized granules will melt at higher temperatures which then delays or restricts gelatinization, less energy will be used to disorganize its structure (Santos and others 2008).

A short range of gelatinization (ΔT) was seen in breadfruit flours with WBF longer than CBF. Nwokocha and Williams (2011) reported a similar, but slightly shorter range for breadfruit

starch (6.07). This is due to two reasons: (1) availability of starch for gelatinization and (2) how it may be compartmentalized within the flour system by fiber, the second having a minimal effect on ΔT . The milling process of flour grounded fiber into small enough particles to prevent starch compartmentalization. Water was then easily available for each starch granule population, preventing extended gelatinization upon heating. PHI represents the uniformity in gelatinization, this is related to the degree of symmetry of the endotherm shape. Lower PHI in WBF is due to higher fiber content in flour, though water availability also effects PHI as it may decrease ΔH and increase T_r , the latter is less likely to occur (Eliasson 1980; Wang and others 2011).

Water Holding Capacity (WHC)

The effects of temperature on water holding capacity (WHC) for WBF and CBF are presented in Fig 2.2. The terms WHC and swelling power are sometimes used interchangeably, WHC is water held by all flour components and swelling power is the amount of water held by starch granules due to heating. WHC of WBF was greater than CBF below 70 °C. A WHC increase was observed for both breadfruit flours at 80 °C, CBF (9.78 ± 0.1 g/g) had higher WHC than WBF (9.16 ± 0.0 g/g). WHC continued to increase at 90 °C for WBF (11.58 ± 0.1 g/g) and CBF (12.66 ± 0.1 g/g). This may be due to the starch content difference between breadfruit flours. This trend agreed with Chandrashekar and Kirleis (1988), they found that sorghum flour had higher WHC than sorghum starch, however when samples approached gelatinization temperatures, starch had significantly higher WHC than flour. Prior to gelatinization, non-starch components such as fiber and proteins absorbed more water than starch as evidence by WHC was greater in WBF than CBF. As breadfruit flours approached gelatinization temperatures

(78 to 79 °C), water absorption increased and starch granules swelled, causing WHC to be greater in CBF than WBF. The effects of temperature on WHC of breadfruit flours is important for viscous foods such as soups, sauces, and gravies. A higher WHC in flour indicates less flour is needed to thicken and improve consistency in many liquid and semi-liquid foods.

Starch Retrogradation

The DSC thermographs of WBF and CBF exhibited a straight line for flour samples after 2 and 4 days at 5 °C, indicating no retrogradation occurred within 4 days of storage (data not shown). One potential reason is the very low amylose breadfruit cultivar used in the flour. AM chains recrystallize immediately after cooling whereas, AP chains take hours or days. The difference in recrystallization speed is due to the linearity of AM and complex branching of AP structures. However, the low AM is not the sole factor that inhibited retrogradation since AP crystallizes faster when stored in temperatures between 4 to 7 °C (Wang and others 2015). Waxy cornstarch used to slow retrogradation in food products is an example of little to no AM starch. Studies have shown waxy cornstarch to recrystallize after 1 or 2 days at low storage temperatures (Eliasson and Ljunger 1988; Fredriksson and others 1998). This indicates another flour component is inhibiting retrogradation.

The presence of non-starch ingredients such as fiber, may also slow retardation due to its water binding capacity. Starch retrogradation can be inhibited or slowed by certain additives or agents that compete with starch for water, or reduce the effectiveness of leached AM to form a gel network (Wang and others 2015). During storage, the fiber in WBF and CBF may have absorbed water that was expelled from the starch system, causing retrogradation to be undetected

by DSC. The changes that occur during starch retrogradation are important in the food industry. Understanding these properties can determine the longevity of food quality and acceptability of finished products. The results indicate that breadfruit flours can potentially be used as an ingredient to extend shelf life of various viscous foods and bakery products.

Least Gelation Capacity (LGC)

WBF and CBF formed a stable gel at 6% (w/v), gel texture was soft at 6%, firm at 8%, and very firm at 12% (data not shown). The LGC data differed from Adepeju and others (2011), WBF (10%) gelled at a higher concentration than CBF (8%). This is probably due to different drying and milling methods employed between our and their flour samples. A lower gelation concentration is ideal for easier texture control for food formulations such as puddings and starch thickened soups and sauces.

Purpose of Tests for Food Applications

The utilization of these tests was used to study possible applications for food formulations as shown in Table 2.3. Flour is used in viscous foods as a thickener or in bakery products such as yeast, quick, and flat breads and pastries. The meaning and results of these tests might help researchers understand the connection between functional and gelatinization properties to food applications.

2.5. Conclusion

The results of this investigation determined that breadfruit flour milled from the mature stage and of the ‘Ma‘afala’ cultivar showed functional properties to be an effective ingredient in building viscosity and retarding retrogradation in many food products such as sauce, soup stock, beverages, and in some bakery formulations. The high carbohydrate and low protein content coupled with good functional and thermal properties make it a possible candidate to work with other gluten-free flours in improving the quality of these specialty products. Breadfruit is abundant and can be produced year-round in tropical countries. Due to its culinary attributes, it is recommended to mill this breadfruit cultivar whole and not just a starch. Of the two flours in terms of functionality, cored breadfruit flour seemed favorable for viscous foods and whole breadfruit flour in bakery products due to non-starch content differences. Thermal data also indicates that breadfruit flour requires high energy to gelatinize, but only needs a short amount of time to cook. Further research is needed to expand functionality knowledge of pulp and whole flours and utility food systems. This includes sensory evaluation of certain breadfruit flour formulations and establishing physicochemical and functional properties of breadfruit flours and starches made from other individual cultivars.

Table 2.1. Functional Properties of Flour and Starch Samples

	Total Fiber Content (g/100g)	Bulk Density (g/mL)	Water Absorption Capacity (g/g)	Oil Absorption Capacity (g/g)
Whole Breadfruit Flour (WBF)	8.60 ± 1.1	0.54 ± 0.0 ^a	2.39 ± 0.1 ^a	1.64 ± 0.2 ^a
Cored Breadfruit Flour (CBF)	6.90 ± 1.2	0.64 ± 0.0 ^{a,b}	2.02 ± 0.0 ^b	1.48 ± 0.1 ^b
All-Purpose Flour ^{1,2}	2.70	0.83 ± 0.1 ^c	1.59 ± 0.0 ^c	1.59 ± 0.0 ^c
Bread Flour ^{1,2}	2.40	0.90 ± 0.0 ^c	1.65 ± 0.0 ^c	1.51 ± 0.0 ^d
Corn Starch ^{1,2}	0.90	0.67 ± 0.1 ^b	ND	ND
Potato Starch ^{1,3}	0.00	0.87 ± 0.1 ^c	ND	ND

Values are expressed as mean ± standard deviation (n=3), Total Fiber Content (WBF: n=9, CBF: n=2).

Values with similar letters within the same column are not significantly different ($p < 0.05$) by Tukey's HSD Test.

ND, Not Determined

¹ Commercially bought

² Total fiber content values as reported by USDA (2016)

³ Total fiber content values as reported by Bednar and others (2001)

Table 2.2. Starch gelatinization properties of breadfruit whole and pulp flour samples by DSC

	T_o (°C)	T_p (°C)	T_c (°C)	ΔT (T _c - T _o)	ΔH (J/g)	PHI
Whole Breadfruit Flour (WBF)	75.3 ± 0.9 ^a	78.2 ± 1.0 ^a	82.5 ± 1.0 ^a	7.2 ± 0.9 ^a	8.6 ± 0.9 ^a	2.97 ^a
Cored Breadfruit Flour (CBF)	76.9 ± 0.3 ^b	79.3 ± 0.4 ^b	83.7 ± 0.7 ^b	6.8 ± 0.6 ^a	10.6 ± 0.6 ^b	4.42 ^b

T_o, Onset Temperature; T_p, Peak Temperature; T_c, Conclusion Temperature; ΔT, Range; ΔH, Gelatinization Enthalpy; PHI, Peak Height Index.

Values are expressed as mean ± standard deviation (WF: n=12, PF: n=11).

Values with similar letters within the same row are not significantly (p<0.05) different.

Table 2.3. Interpretation of Individual Tests for Food Applications

Test	Interpretation of Tests	Test Useful For:			
		Viscous Foods (Soups, sauces, gravies, puddings, etc.)	Bakery Products (Yeast, quick, flat breads, etc.)	High/Longer	Low/Shorter
Total Fiber Content	A higher total fiber content would require more water and/or lipids to improve food product palatability.	NR	Whole Breadfruit Flour (WBF)	Rough/Dry Texture	NR
Bulk Density	For measuring weight of flour or starch ingredients for new food formulations using a volume container (i.e. measuring cups or spoons).	Cored Breadfruit Flour (CBF)	Whole Breadfruit Flour (WBF)	NR	NR
Water Absorption Capacity (WAC)	The amount of water needed for formulating doughs with limited water. Higher WAC indicates more water is needed to improve consistency and texture of food products. Low water may produce a product with a drier mouthfeel while too much water may result in a gummy texture.	NR	Whole Breadfruit Flour (WBF)	Gummy Texture	Dry Mouthfeel
Oil Absorption Capacity (OAC)	The amount of oil that dough formulations can hold. Higher OAC indicates more oil can be added to improve palatability and texture of food products. Low oil may have a crumblier and drier texture while too much oil may result in a greasy mouthfeel.	NR	Whole Breadfruit Flour (WBF)	Crumblier/Dry Texture	Greasy Mouthfeel

NR, Not Recommended

Table 2.3. (Continued) Interpretation of Individual Tests for Food Applications

Gelatinization	The amount of energy and time needed to cook the starch in a food product. If temperature or time is not high enough or long enough, starch granules are undercooked, resulting in raw flour/starch taste. Overcooking starch will disintegrate the granule structure which leads to a “thin” viscous product.	Cored Breadfruit Flour (CBF)	NR	Overcooked "Thin" Consistency	Undercooked Raw Flour Flavor
Retrogradation	All starches undergo this process, but the question is when. When starch begins to retrograde, water is expelled from its structure, resulting in a drier or unpalatable food product. Acceptability of food products benefit from longer inhibition of retrogradation.	Cored Breadfruit Flour (CBF)	Whole Breadfruit Flour (WBF)	Recommended (Longer time)	Staling or aging of breads Thin water layer on viscous foods
Water Holding Capacity (WHC)	The amount of excess water that flour can hold when gelatinization occurs. Higher WHC is preferred, this indicates less flour is needed to thicken viscous foods to desired consistency. Adding too much flour would cause the food product to become “stiff”.	Cored Breadfruit Flour (CBF)	NR	"Stiff" Consistency	Watery Consistency
Least Gelation Capacity (LGC)	The amount of flour/starch to create a strong gel when cooked past gelatinization in excess water. This test indicates the amount of flour/starch is needed to thicken food products. The higher the concentration means more flour/starch is needed to thicken viscous food products.	Cored Breadfruit Flour (CBF)	NR	"Stiff" Consistency	Watery Consistency

NR, Not Recommended

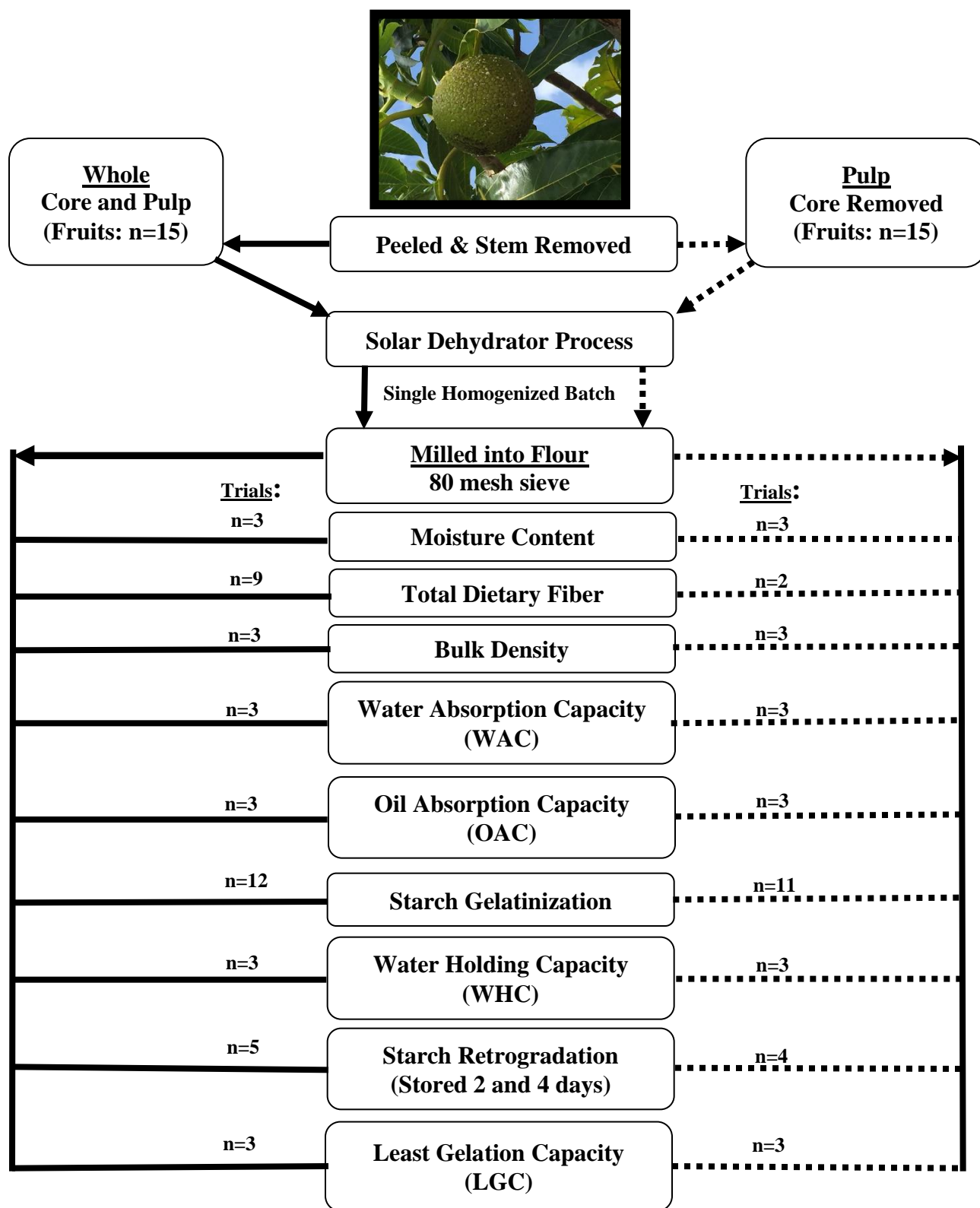


Figure 2.1. Schematic of breadfruit (whole and cored) flour preparation and experiments

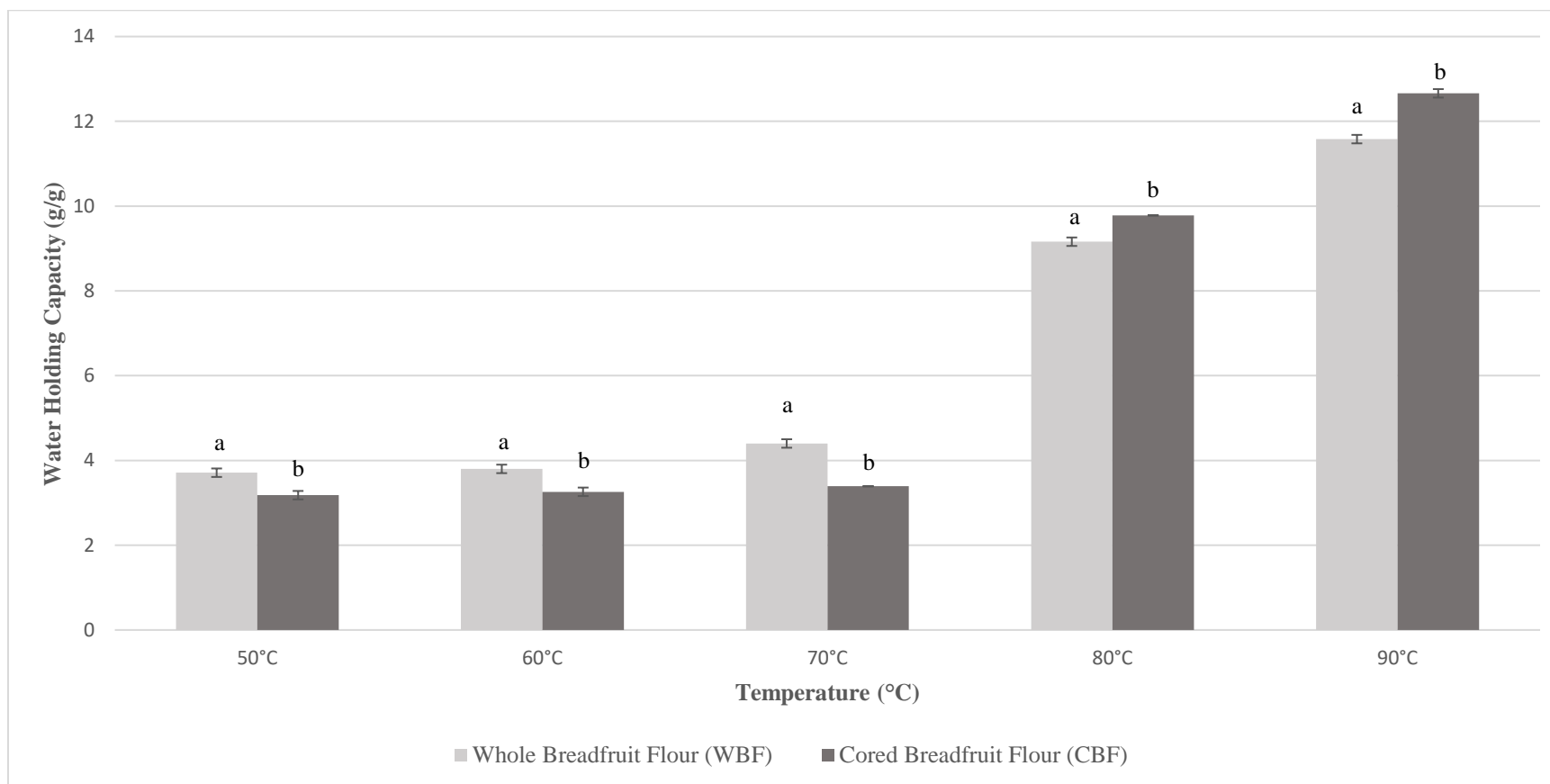


Figure 2.2. Water Holding Capacity (WHC) of Whole Breadfruit Flour (WBF) and Cored Breadfruit Flour (CBF). Values expressed are mean \pm standard deviation (n=3). Values with similar letters within the same row are not significantly ($p < 0.05$) different.

CHAPTER 3

GENERAL CONCLUSION

3.1. General Summary

Breadfruit is a high-energy fruit with a short shelf life and the refrigeration equipment to extend shelf life is uncommonly seen in areas where breadfruit is grown. Therefore drying and milling breadfruit into flour is one possible solution. Breadfruit is underutilized and underappreciated, and not much research has gone into its utility. The overall objective of this research was to investigate and understand the functional, gelatinization, and retrogradation properties of breadfruit whole and cored flour using the ‘Ma‘afala’ cultivar. Whole breadfruit flour (WBF) can potentially be used for bakery products and cored breadfruit flour (CBF) as a thickening agent in many viscous foods due to non-starch content differences. However, breadfruit flour in bakery products works better as a partial flour replacer due to its low protein content. Cooking time is short as evidence by short ΔT of 7.2 and 6.8 for whole and cored flours respectively under high temperature conditions. No retrogradation was found in flour samples stored in cold storage for 2 and 4 days at 5 °C indicating breadfruit flour may be a good ingredient to lengthen shelf life in food products. Understanding the functional and thermal properties of these fruits are important. These findings may help food manufactures or researchers to understand the connection between the experiments to food application uses.

3.2. Future Works

There were some limitations for certain experiments due to funding and not having the equipment to run the test. Other interesting yet potential experiments include.

- ❖ Rapid Visco Analyzer (RVA): An important tool to understand the pasting properties of starches and flours. It can determine the viscosity and texture of slurries and doughs.
- ❖ Longer retrogradation study: As the results showed, breadfruit flours did not retrograde after 2 and 4 days in cold storage. A longer study is needed to determine when they each show signs of retrogradation or whether dietary fiber completely inhibited the process.
- ❖ Cultivar Selection: As researched by various other scientists, individual breadfruit cultivars differ in nutritional and physiochemical properties. A selected few that are strong in certain aspects should be prioritized and used for mass production.
- ❖ Stage of Ripeness: Nutritional content is also changed by ripeness stage. Breadfruit gets sweeter when it ripens, however mature fruits are the most desired due to its bland taste. Determining the stage to pick fruit and mill would be beneficial since some breadfruit cultivars exhibit higher levels of carotenoids at ripe versus mature stage.
- ❖ Sensory Evaluation: The taste and texture profile of various breadfruit based products for consumer favorability.

APPENDIX A. Original and Modifications of Methods

Original Method	Modifications for Chapter 2.
<p><u>Water and Oil Absorption Capacity</u></p> <p>“One gram of each sample in a conical graduated centrifuge tube was thoroughly mixed at high speed in a Waring-Whirl mixer with 50 mL distilled water of 50 mL Crisco Oil. The samples were then allowed to stand at room temperature for 30 min and centrifuged at 5,000 x g for 30 min. The volume of free oil or water was read directly from the graduated centrifuge tube. The amount of oil or water absorbed (total minus free) was multiplied by its density for conversion to grams. Absorption capacity was expressed as the grams of oil or water absorbed (or retained) per gram of sample (as is basis). Density of oil (0.92 g/mL) was determined and water was assumed to have a density of 1 g/mL. Determinations were made in duplicates and average values recorded (Okezie and Bello 1988)”.</p>	<ul style="list-style-type: none"> • 10 mL distilled water or 10 mL canola oil was used. • Samples were homogenized using a vortex mixer (VX 100) for 1 min. • Oil was measured to be 0.88 g/mL.
<p><u>Water Holding Capacity (WHC)</u></p> <p>“Swelling power was determined using 0.32 g of wholemeal or 0.16 g of isolated starch by the modified method of McCormick et al (1991), in which 0.1% AgNO₃ was used instead of distilled water to inhibit α-amylase activity (Yasui et al 1996). Wholemeal or isolated starch was weighed into glass tubes with coated screw caps to which 5 mL of 0.1% AgNO₃ was added. The tubes were placed in a shaking water bath at 70°C for 10 min and transferred into a boiling water bath. After boiling for 10 min, the tubes were cooled in cold water for 5 min and centrifuged at 1,700 × g for 4 min. The supernatant was removed carefully and swelling power was determined as sediment weight (g/g) (Sasaki and Matsuki 1998)”.</p> <p>“Swelling power and solubility were determined using a modification (Kainuma et al 1967) of the method of Leach et al (1959). Mixtures of starch (1 g) and water (50 ml) were heated in plastic centrifuge tubes at 65, 75, 85, and 95 C for 40 min. During heating, the tubes were shaken gently to prevent clumping of the starch. Immediately after centrifuging (3,000 rpm), the carbohydrate in the supernatant was determined colorimetrically (Dubois et al 1956), and the weight of the sediment was recorded. Swelling power was the ratio of the wet mass of the sedimented gel to the dry matter in the gel, and solubility was the percentage of starch dissolved in the continuous fluid phase. The amylose in the soluble phase was determined by iodine-binding capacity, while X_{max} of the iodine complex was determined according to Chrastil (1987) (Takahashi and Seib 1988)”.</p>	<ul style="list-style-type: none"> • 14 mL of distilled water was used. • Samples were homogenized before and during the heating process. • Heated tubes at 50, 60, 70, 80, and 90 °C for 20 mins.

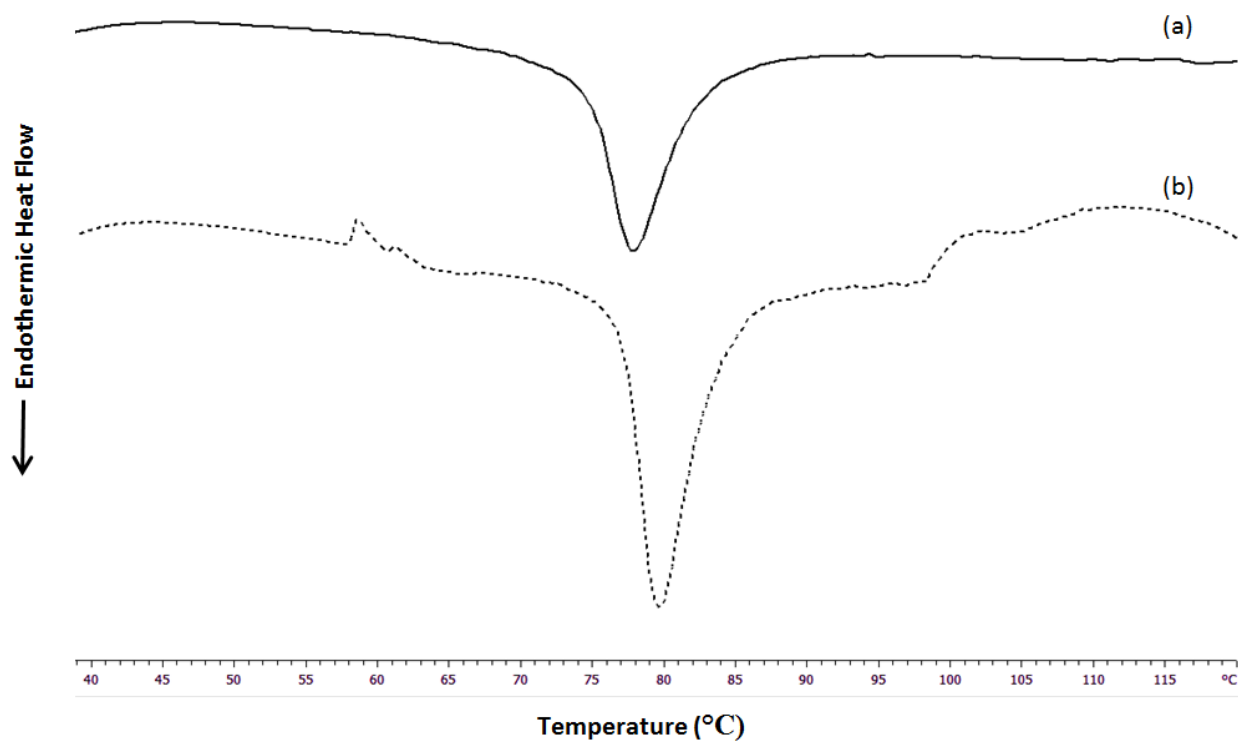
APPENDIX A. (continued) Original and Modifications of Methods

Least Gelation Capacity (LGC)

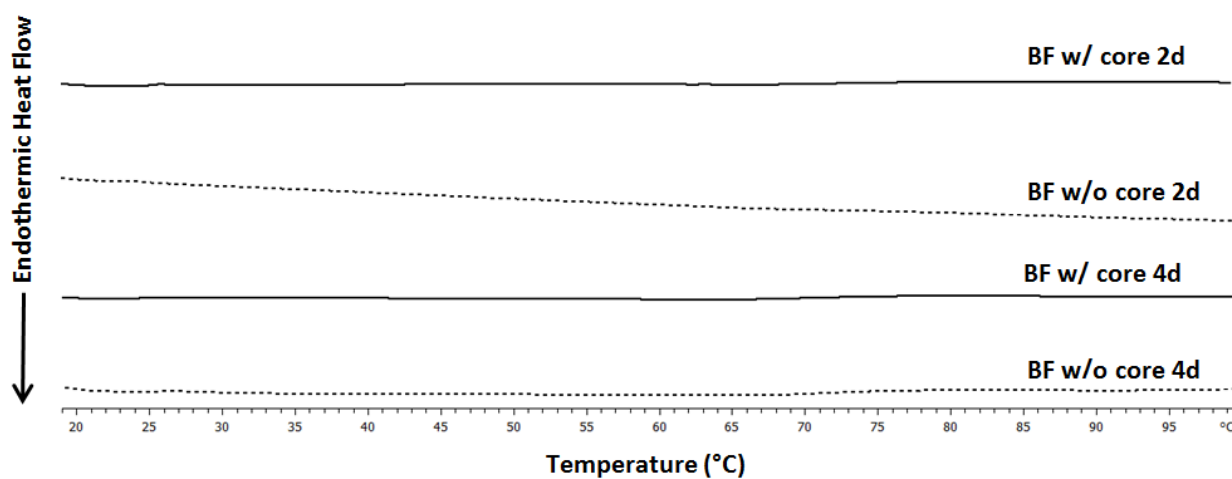
“The method of Coffman and Garcia (1977) was employed with slight modifications. Appropriate sample suspensions of 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20% (w/v) were prepared in 5 ml distilled water. The test tubes containing these suspensions were then heated for 1 hr in a boiling water bath followed by rapid cooling under running cold tap water. The test tubes were then further cooled for 2 hr at 4 °C. The least gelation concentration was determined as that concentration when the sample from the inverted test tube did not fall down or slip (Sathe and Salunkhe 1981)”.

- Flour suspensions of 2, 4, 5, 6, 8, 10, and 12% (w/v) were used.
- Samples were homogenized before and during heating
- Temperature of water bath was 95 ± 2.0 °C.
- Cooled in a cold-water bath.

APPENDIX B. Gelatinization and Retrogradation Thermographs Obtained from Differential Scanning Calorimeter (DSC)



Gelatinization thermographs of (a) Whole breadfruit flour (WBF) and (b) Cored breadfruit flour (CBF) collected from Differential Scanning Calorimetry (DSC)



Retrogradation thermographs of Breadfruit Flours (BF) stored for 2 or 4 days and collected from Differential Scanning Calorimetry (DSC)

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